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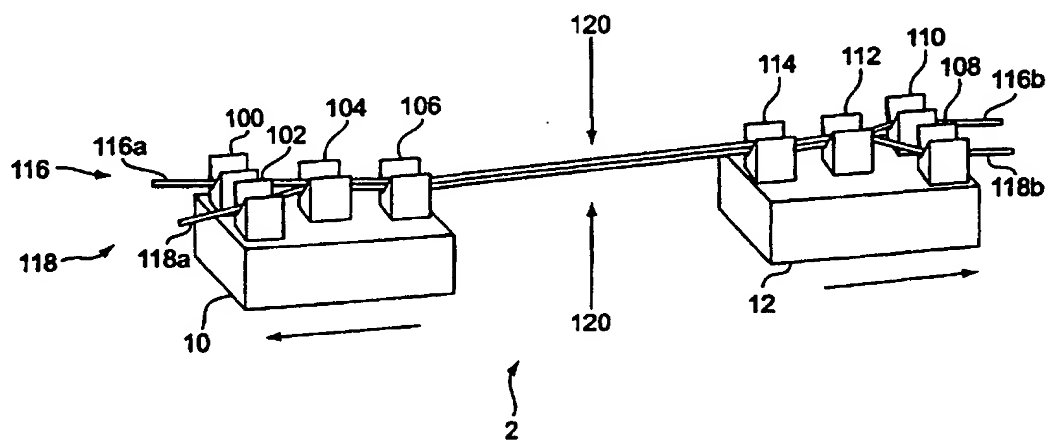
(54) Title: APPARATUS AND METHOD FOR CONTROLLED HEATING AND DEFORMING OF AN OPTIC FIBER



(57) Abstract

A new method of forming a fiber optic device having optical properties is provided. The method includes the sequential, substantially simultaneous or sequence independent steps of applying energy to heat at least one region of at least one optical fiber or optical fiber device using at least one energy source positioned a predetermined distance therefrom, resulting in the deformation of the heated at least one optical fiber or optical fiber device, and monitoring at least one of the optical properties of the at least one optical fiber or optical fiber device. The method also includes the steps of controlling at least one of the energy and the shaping or deforming, responsive to the monitoring step prior to completion of the method, and producing the at least one optical fiber or optical fiber device responsive to the controlling step.

APPARATUS AND METHOD FOR CONTROLLED HEATING AND DEFORMING OF AN OPTIC FIBER

RELATED APPLICATIONS

This application claims priority from U.S. provisional application 60/040,875, filed on March 21, 1997, incorporated herein by reference. This application is a continuation-in-part application of U.S. application serial number 08/718,727, filed on September 24, 1996, incorporated herein by reference.

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to an apparatus and method for controlled heating and deforming of an optical device, such as a waveguide or an optical fiber, and more particularly, to an apparatus and method to accurately and reliably control and monitor the formation of an optical device, such as an optical fiber biconical taper.

Background of the Related Art

Currently, various techniques for stretching, shaping or fusing optical fibers have been performed. For example, one technique involves heating the optical fiber(s) at constant temperature and pulling at a constant rate in an attempt to achieve desired optical properties in the optical fiber or device. Due to the inherent uncertainties in this process, this technique necessitates various estimates or guesses when the heating and pulling should be stopped to achieve the desired properties.

Accordingly, the resulting processed optical fiber(s) or device often times does not meet with the predetermined optical requirements. Thus, this process does not provide good yield results. Further, this crude process limits the types of optical devices that can be produced.

It is therefore desirable to provide accurate and consistent production of high quality fiber optic devices. It is also desirable to provide better device production techniques for a passive fiber optic component manufacturer.

It is further desirable to provide accurate and consistent production of high quality fiber devices, including, for example, an optical fiber biconical taper.

SUMMARY OF THE INVENTION

A feature and advantage of the invention is in providing accurate and consistent production of high quality fiber optic devices.

Another feature and advantage of the invention is that its principal use is, for example, in device production for a passive fiber optic component manufacturer.

Another feature and advantage of the invention is in providing accurate and consistent production of high quality fiber devices, including, for example, an optical fiber biconical taper.

The present invention is based, in part, on the realization or identification of the problem that during standard coupler production, the monitored optical properties, such as coupling ratio, do not accurately correspond to the actual post-production optical properties. This requires that a guess, which must take into account many small variations in production conditions, be made as to the monitored optical properties at which to terminate production of the coupler. This guess creates tremendous uncertainties in the process, thereby lowering the yield of the formation process for fiber optic devices.

Advantageously, I have discovered that the heating temperature and rate of stretch of the optical fiber are main variables that may be beneficially used to achieve accurate formation of optical devices. Further, I have

discovered that the optical properties, such as the coupling ratio, may be beneficially monitored to drive or control the formation or formation conditions of the optical device, such as the heating temperature and/or the rate of stretch of the optical fiber(s).

In accordance with one embodiment of the invention, a new method of forming a fiber optic device having optical properties is provided. The method includes the sequential, substantially simultaneous or sequence independent steps of applying energy to heat at least one region of at least one optical fiber or optical fiber device using at least one energy source positioned a predetermined distance therefrom, resulting in the deformation of the heated at least one optical fiber or optical fiber device, and monitoring at least one of the optical properties of the at least one optical fiber or optical fiber device. The method also includes the steps of controlling at least one of the energy and the shaping or deforming, responsive to the monitoring step prior to completion of the method, and producing the at least one optical fiber or optical fiber device responsive to the controlling step.

An optical fiber or optical fiber device is also provided that is produced by the process.

These together with other objects and advantages which will be subsequently apparent, reside in the details of construction and operation as more fully herein described and claimed, with reference being had to the accompanying drawings forming a part hereof wherein like numerals refer to like elements throughout.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an example of an apparatus to produce fused-biconical tapered couplers;

FIG. 2 is a diagram showing perspective, top and side views of one example of a clamp used this process;

FIG. 3 is a fused biconical taper;

FIG. 4 shows an example of a graph, displaying percentage of optical coupling at a single wavelength between two optical fibers as a function of both stretching distance and stretching time, during the standard production of a fused-biconical tapered (FBT) coupler;

FIG. 5 shows an example of a graph, displaying percentage of optical coupling at a single wavelength between two optical fibers as a function of both stretching distance and stretching time, during the production of a FBT coupler; and

FIG. 6 is another example of a graph, displaying percentage of optical coupling at a single wavelength between two optical fibers as a function of both stretching distance and stretching time, during the production of a FBT coupler.

DESCRIPTION OF PREFERRED EMBODIMENT OF THE INVENTION

The present invention is used on, and provides accurate and reliable production of, optical fibers and fiber optic devices such as couplers, switches, wave-division multiplexers (WDM), filters, attenuators, polarizers, waveguides, and the like, that provide substantially similar optical responses, properties and/or indicators. These various fiber optic devices, such as the WDM, may be constructed of different materials such as glass, crystal, metal, plastic, ceramic and the like.

One principal advantage of this method is that it allows the accurate and consistent production of high quality fiber optic devices. A principal use of this method could be in device production, for example, for a passive fiber optic component manufacturer.

To illustrate this method, I will conceptually discuss the production of a single-wavelength FBT coupler. The production of other fiber optic devices would be similar (with the exception that some steps may

be added and/or omitted based on the specific optical device being formed), including production of single optical fibers and/or devices.

FIG. 1 is an example of an apparatus to produce fused-biconical tapered couplers. This apparatus may also be used for production of single optical fibers and/or devices. The apparatus 2 includes a pair of moveable optical fiber holding stages 10, 12 with a plurality of optical fiber clamps 100-114 attached to the holding stages 10, 12. The optical fiber clamps 100-114 hold a pair of optical fibers 116, 118 in alignment between the holding stages 10, 12.

The fused-biconical tapered coupler (described below in connection with FIG. 2) is produced by heating and fusing together a portion of the stripped section of the optical fibers at area 120 between the holding stages 10, 12. The holding stages 10, 12 are selectively moved apart when the optical fibers are sufficiently heated, thereby stretching the optical fibers. This stretching and heating process facilitates the fusion of the optical fibers together, forming a fused region with generally a biconical taper, for example, at area 120.

Alternative process steps to stretching may also be used so long as the optical fiber or fiber optic device is shaped or formed using such alternative process steps. Thus, the present invention contemplates use of a process step that is able to deform, form, shape, compress or stretch the optical fiber or fiber optic device to alter in the some manner the optical properties relating thereto. Further, the present invention also contemplates various different process steps that control the rate of shaping the optical fiber or fiber optic device.

The optical changes are monitored using standard optical sources and detectors attached to the ends (e.g., 116a, 116b, 118a, 118b) of the optical fibers 116, 118.

Coupler production is terminated when desired optical properties are achieved. Advantageously, I have discovered that the heating temperature and rate of stretch of the optical fibers 116, 118 are main variables that may be beneficially used to achieve accurate formation of optical devices.

The process described herein, beneficially uses the monitored optical property(s) (in this case, the coupling ratio) as a control variable(s) to selectively and variably control the rate of stretching and heat applied to the optical fibers. This process can, of course, also be applied to other optical devices or single optical fibers or devices as discussed above. The variable heating of the optical device may be performed by increasing/decreasing the heat, intensity, power, or energy of the heat source, or by moving the heat source closer/further to/from the optical device, at the same or different regions.

Various types of heat sources can be used, such as lasers, flames, furnaces, electric, and the like, or any other device that can cause the optical fiber or device to be heated. The variable stretching of the optical device may be performed by increasing/decreasing the rate or acceleration of pull by moving, for example, the holding stages further/closer from/to each other. Other techniques or devices for holding and/or stretching the optical fiber or device may also be used.

While the above process describes that the heating, stretching and fusing occur, in part, simultaneously, the present invention also contemplates that the above steps be performed sequentially, and/or independently. The present invention is also based on my realization or postulation that this process is sufficiently effective, in part, when the optical fiber or device is heated generally between its softening and anneal points (e.g., the anneal range), where variation in optical properties

is more stable or less significant. Additionally, the present invention is also based, in part, on my realization or postulation that this process is sufficiently effective when the optical fiber or device is formed or produced while or during a period of time when the heat applied to the optical fiber or device is reduced. Various ranges or values of heating may be used, and/or various heating patterns may also be used.

FIG. 2 is a diagram showing perspective, top and side views of one example of a clamp used in this process. Of course, any standard clamping device may be used. As shown in FIG. 2, the base 100 includes a slot 206 having a width corresponding to the diameter of a bare optical fiber, and a depth corresponding to 1-1/2 times the diameter of an exposed optical fiber. Hence, the slot 206 is adapted to accommodate two optical fibers, where the second exposed optical fiber sits on top of the first optical fiber and is seated halfway within the slot 206. The first optical fiber inserted into the slot 206 is secured by a first vacuum region generated by a first series of vacuum holes 208 located at the base of the slot 206. The base 100 also includes guiding surfaces 210 for guiding an optical fiber into the slot 206. The guiding surfaces 210 also include a second series of vacuum holes 212 for generating a second vacuum region for securing the corresponding surface 210a of the clamp cover 204a to the base 100.

Hence, an exposed optical fiber is secured in the clamp 100 by placing the optical fiber within the vicinity of the guiding surfaces 210. As the optical fiber is lowered into position of the slot 206, the first series of vacuum holes 208 generate a first vacuum region that secures the first optical fiber within the slot 206. A second optical fiber can then be added on top of the first optical fiber within the slot 206. After the first and second optical fibers have been inserted into the

slot 206, the cover 204a is engaged with the base 100. The cover 204a engages the base 100 using a support arm 204b fixed to the cover 204a. The cover 204a has a groove 214 corresponding to the second optical fiber in the slot 206, enabling the first and second optical fibers to be secured within the clamp 100 upon engagement of the cover 204a with the base 100. As recognized in the art, the groove 214 may be substituted with an extension (not shown) that extends into the slot 206 in order to secure a single exposed optical fiber within the primary clamp 100 upon engagement of the cover 204a with the base 100. Hence, different covers 204a may be used, depending on whether one or two optical fibers are to be secured within the clamp 100.

Additional details regarding alternative clamping devices may be found in U.S. Patent No. 5,395,101 to Takimoto et al., the disclosure of which is incorporated in its entirety herein by reference.

FIG. 3 is a fused biconical taper. The biconical taper consists of a pair of tapered regions 122, 124 that guide light between the optical fibers, and an optical coupling region 126. The shape and thickness of the biconical taper, such as the length and slope of the tapered regions and the length and thickness of the optical coupling region, determine the optical properties of the biconical taper. The conditions under which the biconical taper is produced, such as heating temperatures and the rates/accelerations at which the biconical taper is stretched, for example, determine the shape and thickness of the biconical taper. Other variables are also contemplated that may produce equivalent or substantially similar reliable optical responses, properties and/or indicators.

FIG. 4 shows an example of a graph, displaying percentage of optical coupling at a single wavelength between two optical fibers as a function of both

stretching distance and stretching time, during the standard production of a FBT coupler. The standard FBT coupler is produced using a constant heating temperature and a constant rate of stretching; hence, as shown on the graph at area 128, coupling ratio is the same as a function of either stretching distance or stretching time. Line 127 represents the distance of stretch of the optical fiber or device, and line 129 represents the time of stretching the optical fiber or device.

During standard coupler production, the monitored coupling ratio does not accurately correspond to the actual post-production coupling ratio. This requires that a guess, which must take into account many small variations in coupler production conditions, be made as to the monitored coupling ratio at which to terminate production of the coupler. This discrepancy, between the monitored coupling ratio and the post-production coupling ratio, is displayed on the graph as jump 130 in the coupling ratio (shown on the graph between the dashed 50% and 75% lines) as a function of stretching time. That is, when the stretching and resulting stretching distance or length of the optical device is stopped or fixed, the optical properties continue to change in an undetermined, uncontrolled, and/or uncontrollable manner.

FIG. 5 shows an example of a graph, displaying percentage of optical coupling at a single wavelength between two optical fibers as a function of both stretching distance and stretching time, during the production of a FBT coupler using my new method. My new method, after fusing the optical fibers, varies the heating temperature and the rate of stretching to produce the FBT coupler; hence, as shown on the graph, the coupling ratio differs as a function of stretching distance and stretching time. During coupler production using my new method, the monitored coupling ratio does substantially and/or accurately correspond to the actual

post-production coupling ratio, making my new method insensitive to production conditions.

My new method, in response to monitored optical properties, optionally slowly and proportionally decreases both heating temperature and rate of stretching, which decreases the rate of change of the coupling ratio shown at line 134 over time, in comparison with the standard production illustrated at line 132 over distance. Note that distance lines 127 (FIG. 4) and 132 can be substantially similar. My method also allows coupler production to be terminated when, as shown on the graph, the monitored coupling ratio converges on the desired post-production value 136. Note that area 137 is a conceptual representation of the jump that the process described herein was able to avoid by providing the appropriate control from a point substantially early on in the stretching/heating process.

FIG. 6 is another example of a graph, displaying percentage of optical coupling at a single wavelength between two optical fibers as a function of both stretching distance and stretching time, during the production of a FBT coupler using my new method at line 138. This graph displays some of the control possible using my new method. My new method, in response to monitored optical properties, can slowly and proportionally change both heating temperature and rate of stretching, which varies the rate of change of the coupling ratio, and allows complete and accurate control of the coupler production process.

The many features and advantages of the invention are apparent from the detailed specification, and thus, it is intended by the appended claims to cover all such features and advantages of the invention which fall within the true spirit and scope of the invention. Further, since numerous modifications and variations will readily occur to those skilled in the art, it is not

desired to limit the invention to the exact construction and operation illustrated and described, and accordingly, all suitable modifications and equivalents may be resorted to, falling within the scope of the invention.

CLAIMS

What is claimed is:

1. A method of forming a fiber optic device having optical properties, comprising the sequential, substantially simultaneous or sequence independent steps of:

(a) applying energy to heat at least one region of at least one optical fiber or optical fiber device using at least one energy source positioned a predetermined distance therefrom;

(b) stretching the heated at least one optical fiber or optical fiber device using at least one stretching rate;

(c) monitoring at least one of the optical properties of the at least one optical fiber or optical fiber device;

(d) controlling at least one of the energy and the at least one stretching rate, responsive to said monitoring step (c) prior to completion of said method; and

(e) producing the at least one optical fiber or optical fiber device responsive to said controlling step (d).

2. A method according to claim 1, further comprising the step of selectively modifying at least one of the energy and the stretching rate responsive to at least one prescribed optical property.

3. The method of claim 1, wherein said controlling step (d) further comprises the step of variably controlling the energy to the at least one region using the at least one energy source.

4. The method of claim 3, wherein said controlling step (d) further comprises the step of variably controlling the energy to the at least one region by moving the at least one energy source closer to, or further from, the at least one region.

5. The method of claim 1, wherein said controlling step (d) further comprises the step of withdrawing the energy to the at least one region using the at least one energy source.

6. The method of claim 1, wherein said monitoring step (c) further comprises the step of monitoring the at least one of the optical properties including the coupling ratio.

7. The method of claim 6, wherein said controlling step (d) further comprises the step of variably controlling the energy and the stretching rate responsive to a change in the coupling ratio.

8. The method of claim 1, wherein said applying step (a) further comprises the step of applying the energy by moving or applying the at least one energy source axially along the at least one optical fiber or optical fiber device.

9. The method of claim 1, wherein said controlling step (d) further comprises the step of variably controlling the at least one stretching rate.

10. The method of claim 1, wherein said method minimizes at least one of microscopic fractures and/or stress in the at least one optic fiber or optical fiber device.

11. The method of claim 1,

wherein said applying step (a) applies the energy to heat the at least one optical fiber or optical fiber device substantially to about an anneal range or softening range, and

wherein said stretching step (b) stretches the heated at least one optical fiber or optical fiber device substantially at about the anneal range.

12. The method of claim 1, wherein said producing step (e) further comprises the step of producing the at least one optical fiber or optical fiber device including at least one of a wavelength division multiplexer, a

wideband fiber optic coupler, a coupler, a switch, a filter, an attenuator, a polarizer, and a waveguide, responsive to said controlling step (d).

13. The method of claim 1, wherein the optical fiber device comprises at least one of a wavelength division multiplexer, a wideband fiber optic coupler, a coupler, a switch, a filter, an attenuator, a polarizer having the energy applied thereto in said applying step (a).

14. A method of forming a fiber optic device having optical properties, comprising the sequential, substantially simultaneous or sequence independent steps of:

(a) applying energy to heat a region of an optical fiber or optical fiber device using an energy source positioned a predetermined distance therefrom;

(b) deforming or shaping the heated optical fiber or optical fiber device at a stretching rate;

(c) monitoring an optical property of the optical fiber or optical fiber device;

(d) controlling at least one of the energy and the stretching rate, responsive to said monitoring step (c) prior to completion of said method; and

(e) producing the optical fiber or optical fiber device responsive to said controlling step (d).

15. A method of forming a fiber optic device having optical properties, comprising the sequential, substantially simultaneous or sequence independent steps of:

(a) applying energy to heat a region of an optical fiber or optical fiber device using an energy source positioned a predetermined distance therefrom;

(b) deforming or shaping the heated optical fiber or optical fiber device at a stretching rate;

(c) monitoring an optical property of the optical fiber or optical fiber device;

(d) variably controlling at least one of the energy and the stretching rate, responsive to said monitoring step (c); and

(e) producing the optical fiber or optical fiber device responsive to said controlling step (d).

16. A method of forming a fiber optic device having optical properties, comprising the sequential, substantially simultaneous or sequence independent steps of:

(a) placing first and second optical fibers next to each other at a region;

(b) applying energy to heat the first and second optical fibers at a region using an energy source positioned a predetermined distance therefrom;

(c) stretching the heated first and second optical fibers at a stretching rate;

(d) monitoring at least one optical property of the first and second optical fibers;

(e) controlling at least one of the energy and the stretching rate, responsive to said monitoring step (d) prior to completion of said method; and

(f) producing a substantially joined region between the first and second optical fibers to form the fiber optic device responsive to said controlling step (e).

17. A method of forming a fiber optic device having optical properties, comprising the sequential, substantially simultaneous or sequence independent steps of:

(a) applying energy to heat at least one region of at least one optical fiber or optical fiber device using at least one energy source positioned a predetermined distance therefrom;

(b) at least one of shaping and deforming the heated at least one optical fiber or optical fiber device;

(c) monitoring at least one of the optical properties of the at least one optical fiber or optical fiber device;

(d) controlling at least one of the energy and the shaping or deforming, responsive to said monitoring step (c) prior to completion of said method; and

(e) producing the at least one optical fiber or optical fiber device responsive to said controlling step (d).

18. A method of forming a fiber optic device having optical properties, comprising the sequential, substantially simultaneous or sequence independent steps of:

(a) applying energy to heat at least one region of at least one optical fiber or optical fiber device using at least one energy source positioned a predetermined distance therefrom, resulting in the deformation of the heated at least one optical fiber or optical fiber device;

(b) monitoring at least one of the optical properties of the at least one optical fiber or optical fiber device;

(c) controlling at least one of the energy and the shaping or deforming, responsive to said monitoring step (b) prior to completion of said method; and

(d) producing the at least one optical fiber or optical fiber device responsive to said controlling step (c).

19. An optical fiber or optical fiber device produced in accordance with the process of claim 1.

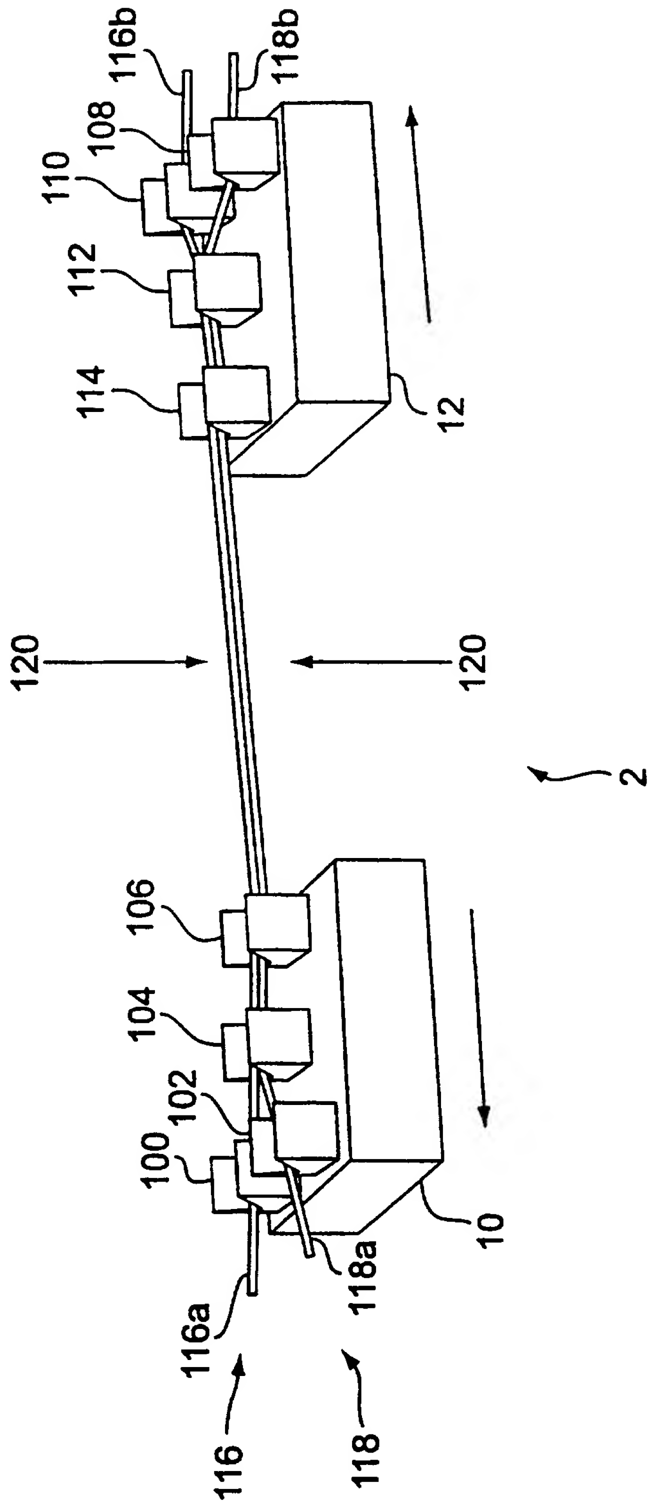
20. An optical fiber or optical fiber device produced in accordance with the process of claim 14.

21. An optical fiber or optical fiber device produced in accordance with the process of claim 15.

22. An optical fiber or optical fiber device produced in accordance with the process of claim 16.

23. An optical fiber or optical fiber device produced in accordance with the process of claim 17.

24. An optical fiber or optical fiber device produced in accordance with the process of claim 18.


116b
118b
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2
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118a
116a
116
118

FIG. 1

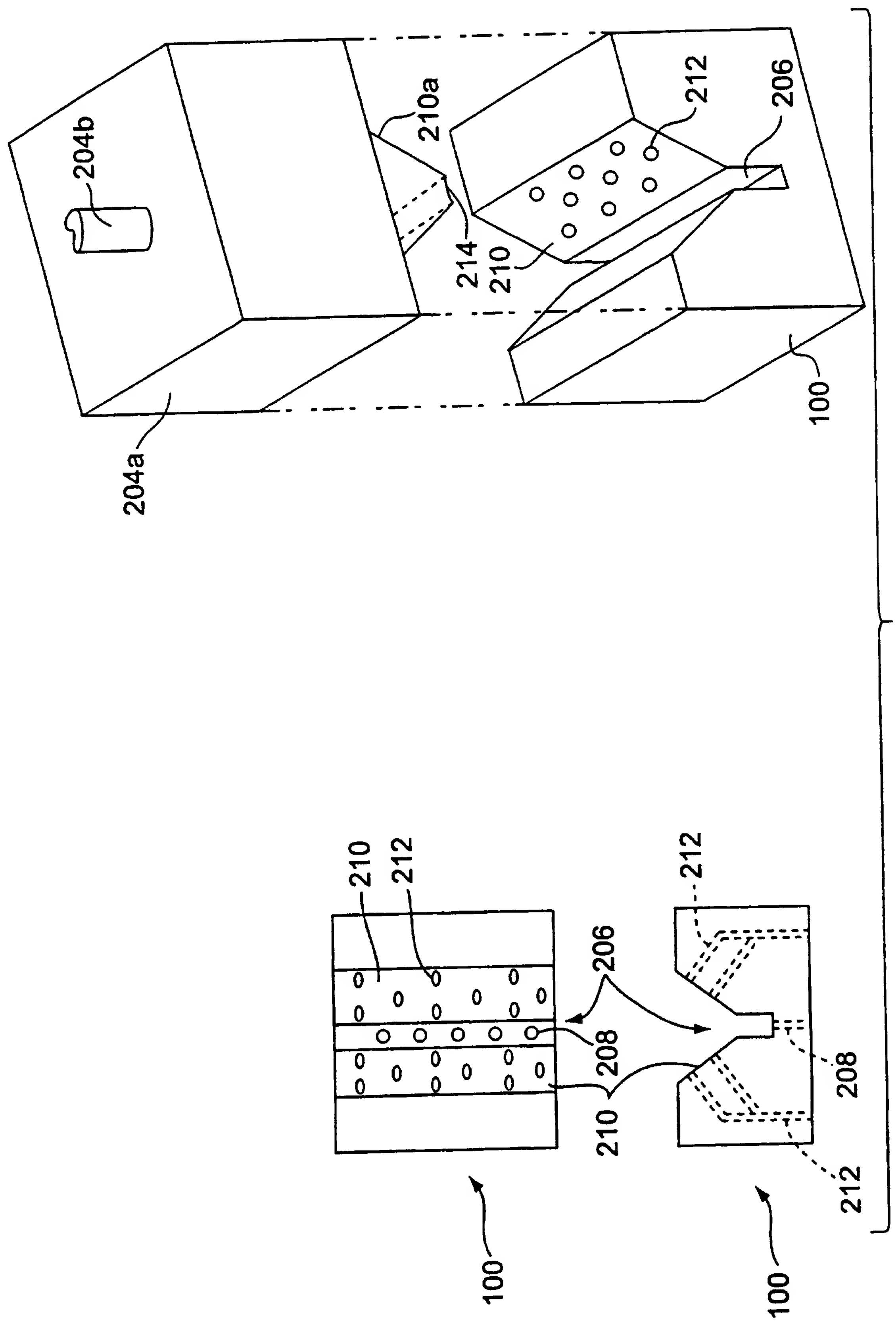
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FIG. 2

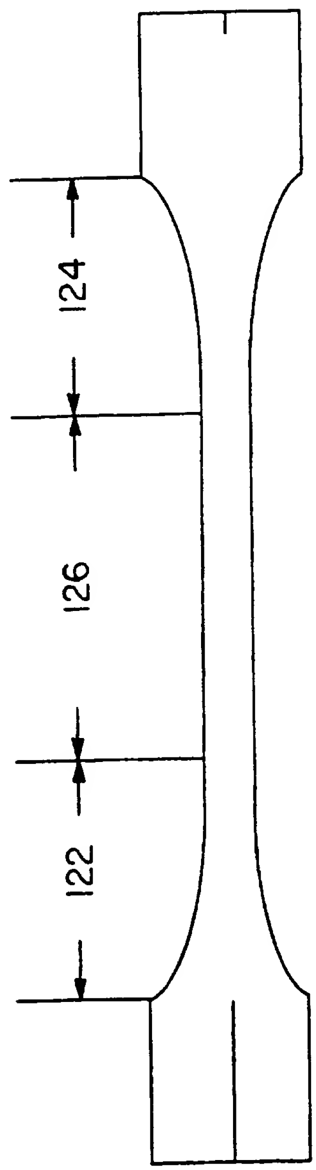
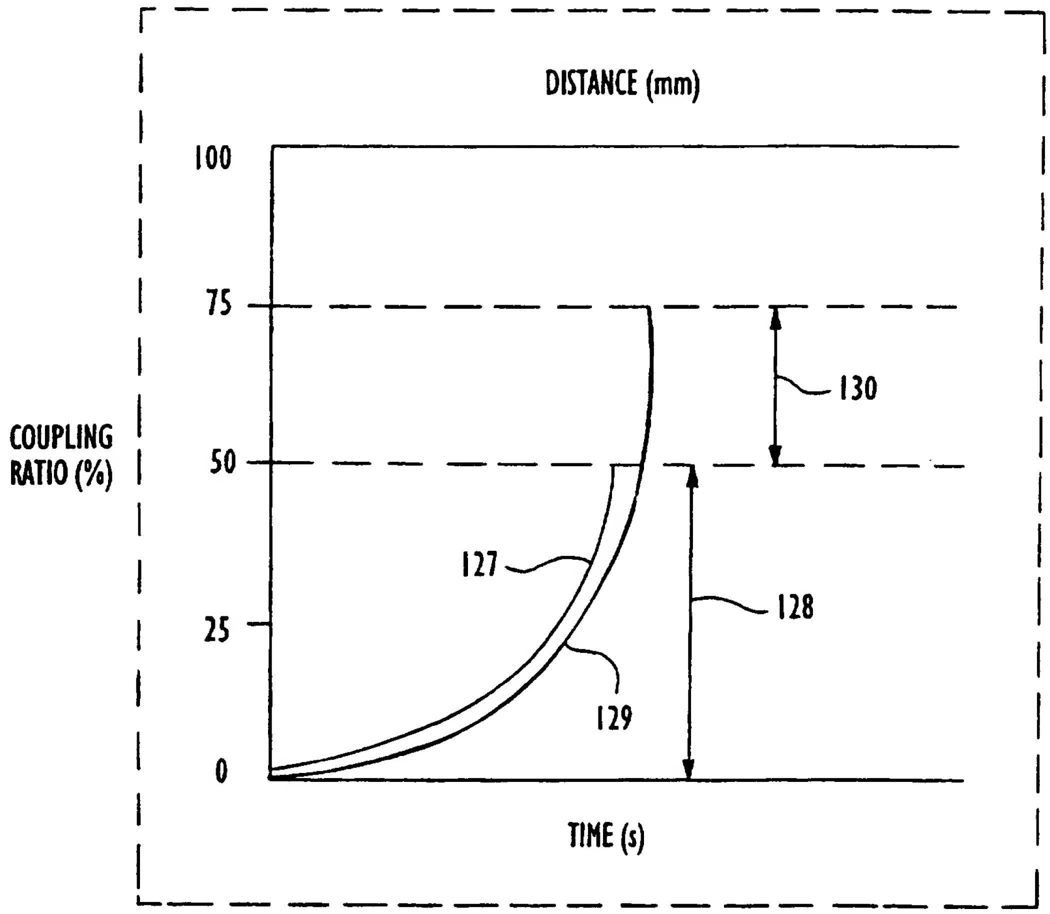


FIG. 3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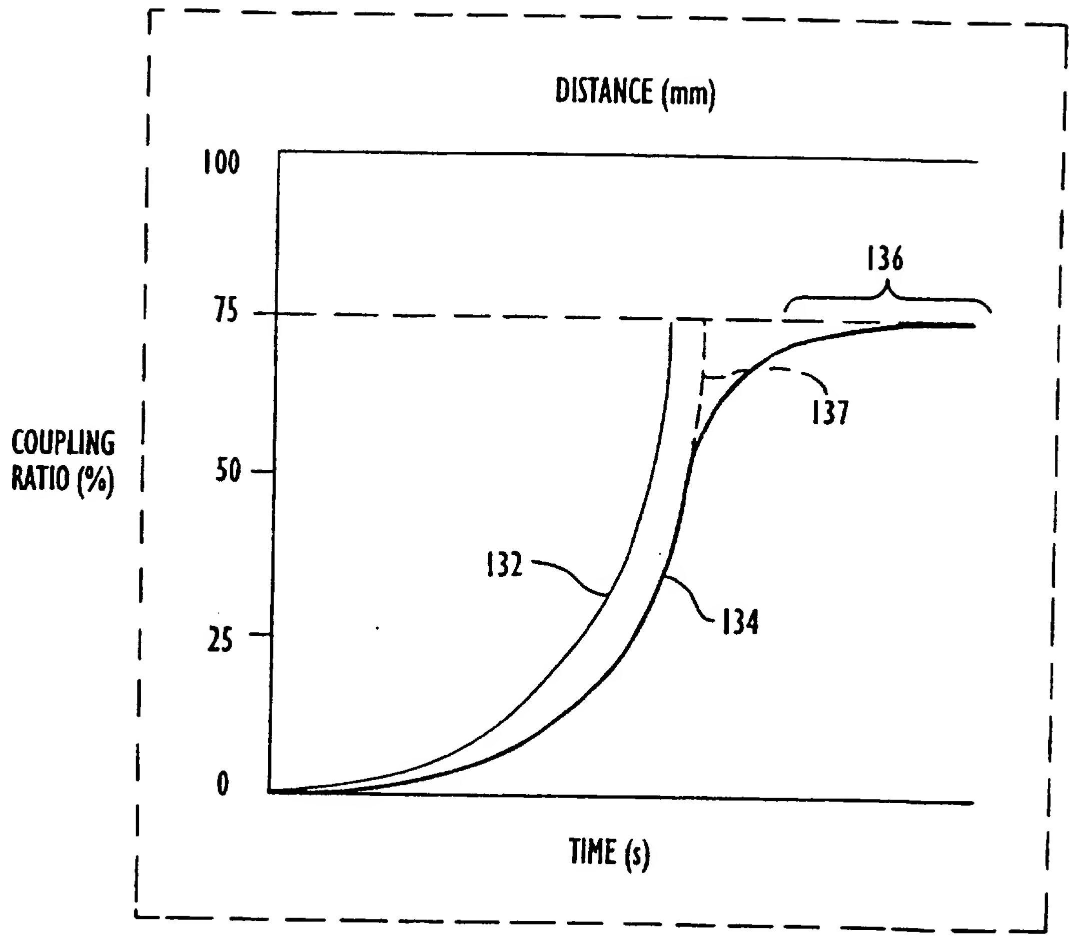
25
0
COUPLING RATIO (%)
130
127
128
129
TIME (s)

FIG. 4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COUPLING RATIO (%)
136
137
132
134
TIME (s)

FIG. 5

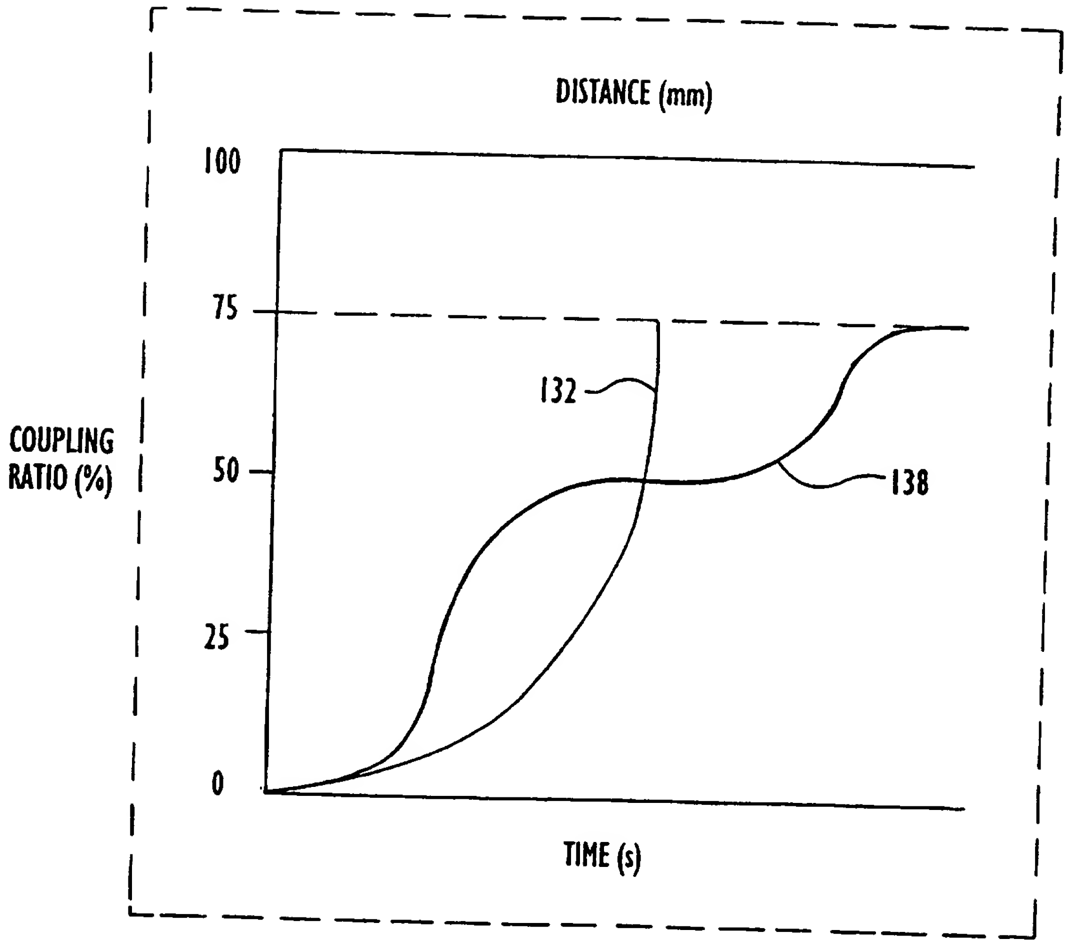

FIG. 6

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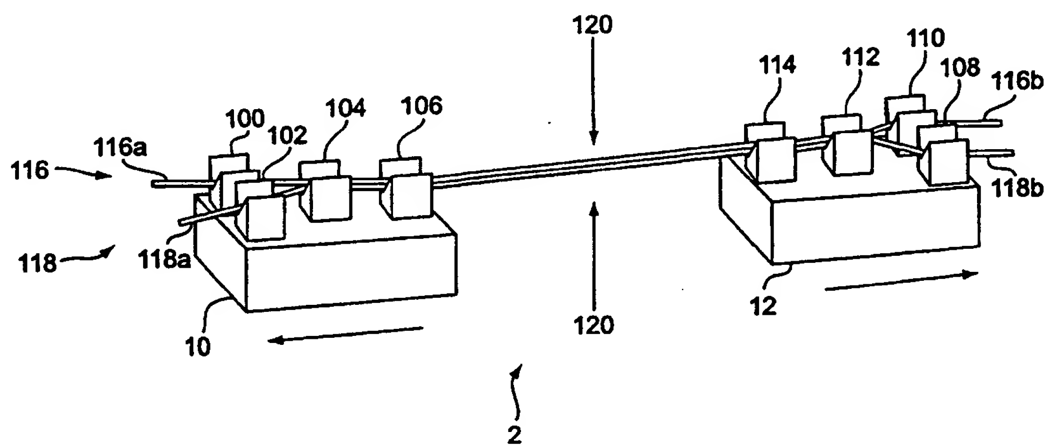

(57) Abstract

A new method of forming a fiber optic device having optical properties is provided. The method includes the sequential, substantially simultaneous or sequence independent steps of applying energy to heat at least one region of at least one optical fiber or optical fiber device using at least one energy source positioned a predetermined distance therefrom, resulting in the deformation of the heated at least one optical fiber or optical fiber device, and monitoring at least one of the optical properties of the at least one optical fiber or optical fiber device. The method also includes the steps of controlling at least one of the energy and the shaping or deforming, responsive to the monitoring step prior to completion of the method, and producing the at least one optical fiber or optical fiber device responsive to the controlling step.

INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G02B6/28

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 895 423 A (BILODEAU FRANCOIS ET AL) 23 January 1990 see abstract; figure 3 see column 4, line 15 - column 5, line 9 ---	1-9,12, 13,16, 19,22
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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

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Date of the actual completion of the international search	Date of mailing of the international search report
19 May 1998	29. 05. 98
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	**Authorized officer** Beaven, G

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	YOSHIAKI TAKEUCHI: "CHARACTERISTICS ANALYSIS OF WAVELENGTH-DIVISION-MULTIPLEXING FIBER COUPLERS FABRICATED WITH A MICROHEATER" APPLIED OPTICS, vol. 35, no. 9, 20 March 1996, pages 1478-1484, XP000559724 see abstract; figures 1,3	1-3,5,6, 12,13, 16,19,22
Y	see page 1479, left-hand column, line 15 - right-hand column, line 27	10,11
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	PATENT ABSTRACTS OF JAPAN vol. 006, no. 092 (P-119), 29 May 1982 & JP 57 027211 A (FUJITSU LTD), 13 February 1982, see abstract; figures 3,4	14,15, 20,21
Y	EP 0 582 894 A (SUMITOMO ELECTRIC INDUSTRIES) 16 February 1994 see abstract; figure 2 see column 1, line 49 - column 2, line 19	14,15, 20,21
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INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 97/16275

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

SEE SEPARATE SHEET

1. ☒ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☒ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Claims 1 - 13, 16, 19, 22 which relate to a method of manufacturing a biconical fibre optic coupler by heating and stretching two fibers and the product of such a method;

Claims 14, 15, 20, 21 which relate to a method of manufacturing a single fiber device by heating and stretching a single fibers and the product of such a method; and

Claims 17, 18, 23 & 24 a method of manufacturing an optical fibre device by heating and deforming (i.e. compressing) at least two optical fibres and the product of such a method.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 97/16275

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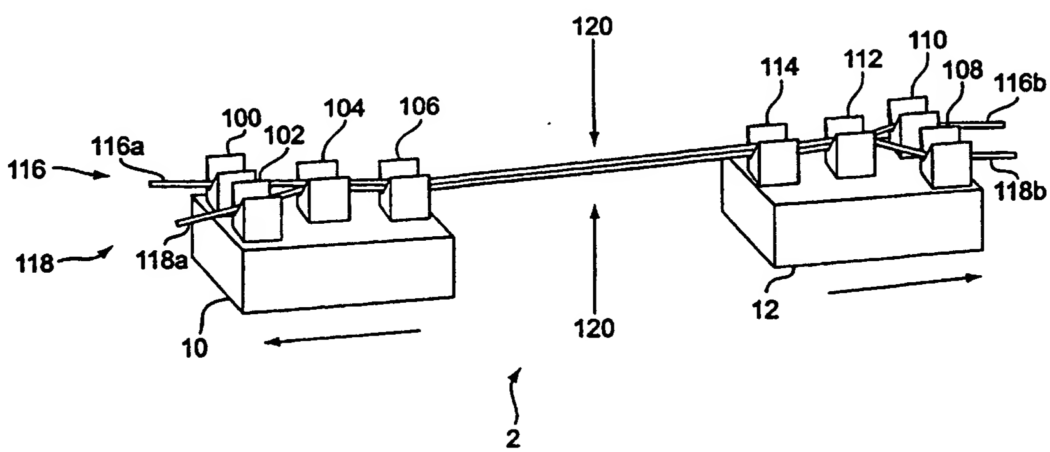
(54) Title: APPARATUS AND METHOD FOR CONTROLLED HEATING AND DEFORMING OF AN OPTIC FIBER



(57) Abstract

A new method of forming a fiber optic device having optical properties is provided. The method includes the sequential, substantially simultaneous or sequence independent steps of applying energy to heat at least one region of at least one optical fiber or optical fiber device using at least one energy source positioned a predetermined distance therefrom, resulting in the deformation of the heated at least one optical fiber or optical fiber device, and monitoring at least one of the optical properties of the at least one optical fiber or optical fiber device. The method also includes the steps of controlling at least one of the energy and the shaping or deforming, responsive to the monitoring step prior to completion of the method, and producing the at least one optical fiber or optical fiber device responsive to the controlling step.

AMENDED CLAIMS

[received by the International Bureau on 28 July 1998 (28.07.98);
original claim 6 cancelled; original claims 1, 14-18 amended; new claims 25-27 added;
remaining claims unchanged (7 pages)]

1. A method of forming a fiber optic device having optical properties, comprising the sequential, substantially simultaneous or sequence independent steps of:

(a) applying energy to heat at least one region of at least one optical fiber or optical fiber device using at least one energy source positioned a predetermined distance therefrom;

(b) stretching the heated at least one optical fiber or optical fiber device using at least one stretching rate;

(c) monitoring at least one of the optical properties of the at least one optical fiber or optical fiber device, the at least one of the optical properties including a coupling ratio;

(d) dynamically controlling at least one of the energy and the at least one stretching rate, responsive to said monitoring step (c) prior to completion of said method; and

(e) producing the at least one optical fiber or optical fiber device responsive to said controlling step (d).

2. A method according to claim 1, further comprising the step of selectively modifying at least one of the energy and the stretching rate responsive to at least one prescribed optical property.

3. The method of claim 1, wherein said controlling step (d) further comprises the step of variably controlling the energy to the at least one region using the at least one energy source.

4. The method of claim 3, wherein said controlling step (d) further comprises the step of variably controlling the energy to the at least one region by moving the at least one energy source closer to, or further from, the at least one region.

5. The method of claim 1, wherein said controlling step (d) further comprises the step of withdrawing the energy to the at least one region using the at least one energy source.

7. The method of claim 6, wherein said controlling step (d) further comprises the step of variably controlling the energy and the stretching rate responsive to a change in the coupling ratio.

8. The method of claim 1, wherein said applying step (a) further comprises the step of applying the energy by moving or applying the at least one energy source axially along the at least one optical fiber or optical fiber device.

9. The method of claim 1, wherein said controlling step (d) further comprises the step of variably controlling the at least one stretching rate.

10. The method of claim 1, wherein said method minimizes at least one of microscopic fractures and/or stress in the at least one optic fiber or optical fiber device.

11. The method of claim 1,

wherein said applying step (a) applies the energy to heat the at least one optical fiber or optical fiber device substantially to about an anneal range or softening range, and

wherein said stretching step (b) stretches the heated at least one optical fiber or optical fiber device substantially at about the anneal range.

12. The method of claim 1, wherein said producing step (e) further comprises the step of producing the at least one optical fiber or optical fiber device including at least one of a wavelength division multiplexer, a wideband fiber optic coupler, a coupler, a switch, a filter, an attenuator, a polarizer, and a waveguide, responsive to said controlling step (d).

13. The method of claim 1, wherein the optical fiber device comprises at least one of a wavelength division multiplexer, a wideband fiber optic coupler, a coupler, a switch, a filter, an attenuator, a polarizer having the energy applied thereto in said applying step (a).

14. A method of forming a fiber optic device having optical properties, comprising the sequential, substantially simultaneous or sequence independent steps of:

(a) applying energy to heat a region of an optical fiber or optical fiber device using an energy source positioned a predetermined distance therefrom;

(b) deforming or shaping the heated optical fiber or optical fiber device at a stretching rate;

(c) dynamically monitoring an optical property of the optical fiber or optical fiber device, the optical property including a coupling ratio;

(d) controlling at least one of the energy and the stretching rate, responsive to said monitoring step (c) prior to completion of said method; and

(e) producing the optical fiber or optical fiber device responsive to said controlling step (d).

15. A method of forming a fiber optic device having optical properties, comprising the sequential, substantially simultaneous or sequence independent steps of:

(a) applying energy to heat a region of an optical fiber or optical fiber device using an energy source positioned a predetermined distance therefrom;

(b) deforming or shaping the heated optical fiber or optical fiber device at a stretching rate;

(c) monitoring an optical property of the optical fiber or optical fiber device, the optical property including a coupling ratio;

(d) dynamically, variably controlling at least one of the energy and the stretching rate, responsive to said monitoring step (c); and

(e) producing the optical fiber or optical fiber device responsive to said controlling step (d).

16. A method of forming a fiber optic device having optical properties, comprising the sequential, substantially simultaneous or sequence independent steps of:

(a) placing first and second optical fibers next to each other at a region;

(b) applying energy to heat the first and second optical fibers at a region using an energy source positioned a predetermined distance therefrom;

(c) stretching the heated first and second optical fibers at a stretching rate;

(d) monitoring at least one optical property of the first and second optical fibers, the at least one optical property including a coupling ratio;

(e) dynamically controlling at least one of the energy and the stretching rate, responsive to said monitoring step (d) prior to completion of said method; and

(f) producing a substantially joined region between the first and second optical fibers to form the fiber optic device responsive to said controlling step (e).

17. A method of forming a fiber optic device having optical properties, comprising the sequential, substantially simultaneous or sequence independent steps of:

(a) applying energy to heat at least one region of at least one optical fiber or optical fiber device using at least one energy source positioned a predetermined distance therefrom;

(b) at least one of shaping and deforming the heated at least one optical fiber or optical fiber device;

(c) monitoring at least one of the optical properties of the at least one optical fiber or optical fiber device, the at least one of the optical properties including a coupling ratio;

(d) dynamically controlling at least one of the energy and the shaping or deforming rate, responsive to said monitoring step (c) prior to completion of said method; and

(e) producing the at least one optical fiber or optical fiber device responsive to said controlling step (d).

18. A method of forming a fiber optic device having optical properties, comprising the sequential, substantially simultaneous or sequence independent steps of:

(a) applying energy to heat at least one region of at least one optical fiber or optical fiber device using at least one energy source positioned a predetermined distance therefrom, resulting in the deformation of the heated at least one optical fiber or optical fiber device;

(b) monitoring at least one of the optical properties of the at least one optical fiber or optical fiber device, the at least one of the optical properties including a coupling ratio;

(c) dynamically controlling at least one of the energy and the shaping or deforming rate, responsive to said monitoring step (b) prior to completion of said method; and

(d) producing the at least one optical fiber or optical fiber device responsive to said controlling step (c).

19. An optical fiber or optical fiber device produced in accordance with the process of claim 1.

20. An optical fiber or optical fiber device produced in accordance with the process of claim 14.

21. An optical fiber or optical fiber device produced in accordance with the process of claim 15.

22. An optical fiber or optical fiber device produced in accordance with the process of claim 16.

23. An optical fiber or optical fiber device produced in accordance with the process of claim 17.

24. An optical fiber or optical fiber device produced in accordance with the process of claim 18.

25. A method of forming a fiber optic device from first and second optical fibers contacting each other at a region, comprising the sequential or non-sequential steps of:

providing incident heat on the first and second optical fibers at the region;

pulling the heated first and second optical fibers at a first velocity at a variable tension;

monitoring a change of a coupling ratio between the first and second optical fibers;

dynamically reducing the provided incident heat on the first and second optical fibers or dynamically adjusting the first velocity when the change in the coupling ratio is detected between the first and second optical fibers; and

selectively repeating at least one of said reducing step and said adjusting step when the change in the coupling ratio is detected.

26. A method of forming a fiber optic device from first and second optical fibers contacting each other at a region, comprising the sequential or non-sequential steps of:

providing incident heat on the first and second optical fibers at the region;

pulling the heated first and second optical fibers at a velocity under a variable tension;

monitoring a change of a coupling ratio between the first and second optical fibers, the change in the coupling ratio varying between an initial coupling ratio and a desired coupling ratio;

dynamically reducing the provided incident heat on the first and second optical fibers or dynamically adjusting the velocity when the change in the coupling ratio is detected between the first and second optical fibers at any coupling ratio value between the initial coupling ratio to the desired coupling ratio; and

dynamically and selectively repeating at least one of said reducing step and said adjusting step when the change in the coupling ratio is detected at any coupling ratio value betwee the initial coupling ratio to the desired coupling ratio.

27. A method according to claim 26, wherein the change in coupling ratio comprises at least a substantial change in the coupling ratio.